Was the X-ray Afterglow of GRB 970815 Detected?

N. Mirabal*, J. P. Halpern*, E. V. Gotthelf* and R. Mukherjee†

*Astronomy Department, Columbia University, 550 West 120th Street, New York, NY 10027
†Dept. of Physics & Astronomy, Barnard College, New York, NY 10027

Abstract. GRB 970815 was a well-localized gamma-ray burst (GRB) detected by the All-Sky Monitor (ASM) on the Rossi X-Ray Timing Explorer (RXTE) for which no afterglow was identified despite follow-up *ASCA* and *ROSAT* pointings and optical imaging to limiting magnitude $R > 23$. While an X-ray source, AX/RX J1606.8+8130, was detected just outside the ASM error box, it was never associated with the GRB because it was not clearly fading and because no optical afterglow was ever discovered. We recently made deep optical observations of the AX/RX J1606.8+8130 position, which is blank to a limit of $V > 24.3$ and $I > 24.0$, implying an X-ray–to–optical flux ratio $f_X/f_V > 500$. In view of this extreme limit, we analyze and reevaluate the *ASCA* and *ROSAT* data and conclude that the X-ray source AX/RX J1606.8+8130 was indeed the afterglow of GRB 970815, which corresponds to an optically "dark" GRB. Alternatively, if AX/RX J1608+8130 is discovered to be a persistent source, then it could be associated with EGRET source 3EG J1621+8203, whose error box includes this position.

INTRODUCTION

One of the most intriguing results from six years of GRB follow-ups at optical wavelengths is that roughly 60% of well-localized GRBs lack an optical transient despite intensive ground-based searches (e.g. [3]). Some of these "dark" GRBs could simply be due to a failure to image deeply or quickly enough. However, in certain cases the afterglow may have been missed in the optical either because it is obscured by dust in the host galaxy, or because it is located at high-redshift ($z > 5$). We discuss here X-ray and optical observations of GRB 970815, which support an interpretation consistent with quite possibly the first detection of a "dark" GRB in the afterglow era, preceding GRB 970828 in that category [1].

X-RAY OBSERVATIONS

GRB 970815 was localized by the ASM aboard RXTE on UT 1997 Aug. 15.50623, with a duration of $\approx$ 130 s [9]. Simultaneous detection with two of the ASM scanning cameras refined the position of GRB 970815 to the small error box shown in Figure 1. The superposed annulus based on the BATSE and Ulysses triangulation confirms the ASM position. Following the prompt localization by *RXTE*, two X-ray observations were made that cover the entire *RXTE* error box, one by *ASCA* [8] and one by the *ROSAT* High Resolution Imager (HRI) [4]. Analysis of the data revealed

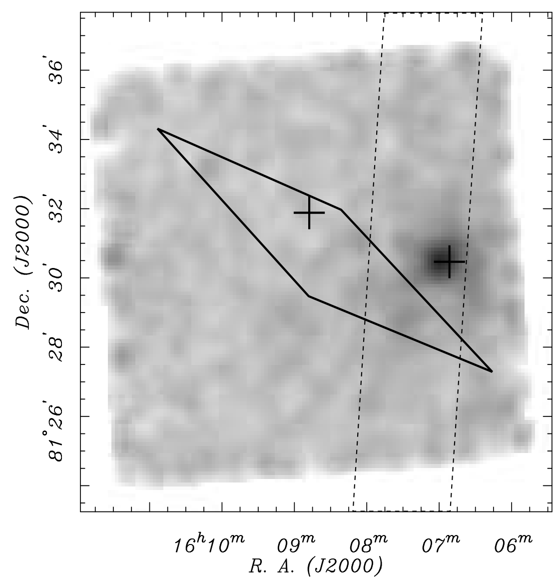

FIGURE 1. *ASCA* CCD SIS image of the field of GRB 970815, with the *RXTE* ASM error box (*solid line*) and Ulysses/BATSE annulus (*dashed lines*) superposed. *ROSAT* HRI point sources are indicated by *crosses*.

no source brighter than 1×10^{-13} erg cm^{-2} s^{-1} within the *RXTE* error box. There was, however, a source AX/RX J1606.8+8130 just outside the *RXTE* error box with an average flux F_x(2–10 keV) = 4.2×10^{-13} erg cm^{-2} s^{-1}. Figure 1 shows the combined *ASCA* SIS image and the location of AX/RX J1606.8+8130 with respect to the burst error box. While AX/RX J1606.8+8130 lies just outside the *RXTE* error box, it is within the BATSE/Ulysses annulus. Another marginally significant *ROSAT* source RX J1608.8+8131 lies inside the *RXTE* error box, but it was not detected in the earlier *ASCA* observation. Hereafter we concentrate our discussion on AX/RX J1606.8+8130.

X-RAY LIGHT CURVE

Figure 2 shows the combined X-ray light curve of AX/RX J1606.8+8130. The *ASCA* light curve includes the sum of counts from all four detectors. The *ROSAT* points correspond to an extrapolated flux in the 2–10 keV band assuming the power-law spectral parameters derived from the *ASCA* spectra ($\Gamma = 1.64 \pm 0.35$ and $N_{\rm H} < 1.3 \times 10^{21}$ cm^{-2}), which might not be entirely valid if an additional spectral component contributes significantly in the HRI soft band. The individual *ASCA* and *ROSAT* components of the light curve show no obvious evidence for variability. However, AX/RX J1606.8+8130 is consistent with a $F_x \propto t^{-1.4}$ flux decay between the *ASCA* and *ROSAT* observations, easily within the range of well-studied GRB X-ray afterglows. Moreover, the integrated 2–10 keV X-ray fluence corresponds to $\approx 10\%$ of the GRB fluence, in agreement with the properties of other GRBs [2].

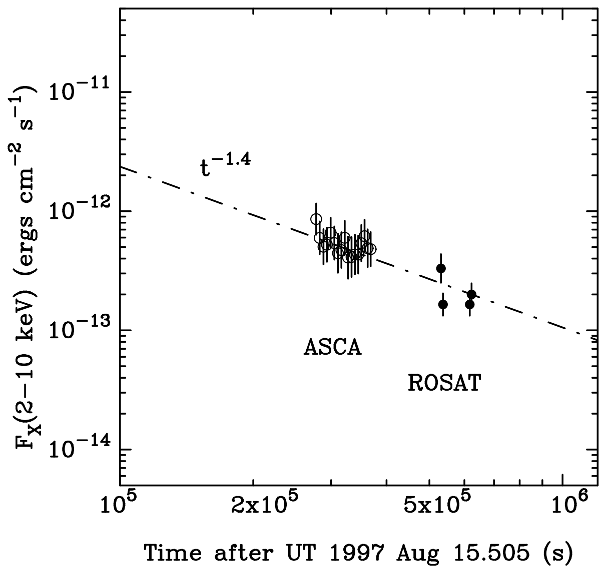

FIGURE 2. The X-ray light curve of AX/RX J1606.8+8130, derived by assuming the simultaneous power-law fit to the *ASCA* spectra. The *dash-dot* line shows a simple power-law decay $F_x \propto t^{-1.4}$, although the variation in the *ASCA* points are also consistent with no overall decay.

OPTICAL OBSERVATIONS OF AX/RX J1606.8+8130

Following the rapid dissemination of the *RXTE* position for GRB 970815, a number of groups conducted optical imaging of its error box including the position of AX/RX J1606.8+8130 as early as 17 hr after the burst [5]. At the time, no significant variable sources were found at the X-ray position or within the *RXTE* error box to an upper limit $R > 23$ [5]. Years later while conducting a search for the γ-ray source 3EG J1621+8203 [7], we reexamined the X-ray position of AX/RX J1606.8+8130 in several optical filters. Figure 3 shows the adopted $10''$ radius *ROSAT* error circle around the X-ray position, which is still optically blank to a 3σ limit of $V > 24.3$. In other filters, AX/RX J1606.8+8130 shows no evidence of a host galaxy or any other optical counterpart to limits of $B > 21.5$, $R > 22.0$, and $I > 24.0$.

WAS AX/RX J1606.8+8130 THE AFTERGLOW OF GRB 970815?

Starting with the observed X-ray flux density f_X, we can extrapolate a broad-band spectrum of the form $f_R = f_X(\nu_R/\nu_X)^{-\beta}$ where f_R is the R-band optical flux density at a frequency ν_R and β is the X-ray spectral index. From the *ASCA* spectra we have $f_X \approx 0.10\,\mu$Jy ($\nu_X = 4.84 \times 10^{17}$ Hz) at a time $t \sim 3.74$ days after the burst, and $\beta \approx 0.64$. The optical flux density evolution would then correspond to $f_R(t_d) \approx 55\,t_d^{-1.4}\,\mu$Jy where t_d is days elapsed since the BATSE detection of GRB 970815. This translates into $R \approx 19.0$ on UT 1997 Aug. 16.31. Therefore, the predicted magnitude is brighter than the $R > 23$ upper limit reported at that time [5]. Such difference would tentatively support a

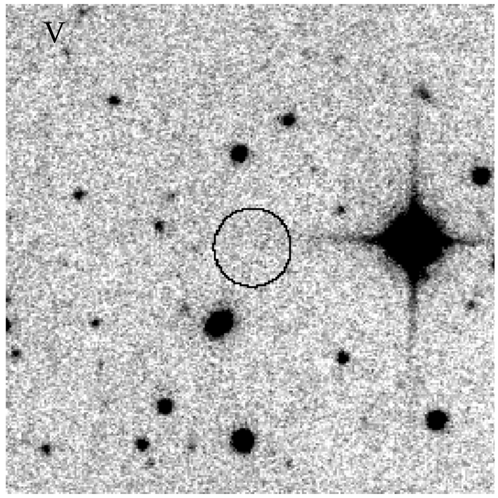

FIGURE 3. Zoom-in on a deep V image from the MDM Observatory at the location of the unidentified X-ray source AX/RX J1606.8+8130. The field is $2'$ across, and the *ROSAT* HRI error circle is $10''$ in radius. The 3σ upper limit is $V > 24.3$. North is up and east is to the left.

"dark" GRB classification. Nonetheless, the chance superposition of 3EG J1621+8203 and GRB 970815 introduces a slight doubt about the nature of AX/RX J1606.8+8130. This is because "dark" GRBs can temporarily mimic the characteristics of a plausible counterpart for unidentified EGRET sources, namely, rotation-powered pulsars [6].

CONCLUSIONS AND FUTURE WORK

In summary, the properties of AX/RX J1606.8+8130 support the idea that GRB 970815 corresponds to an optically "dark" GRB, quite possibly the first detection of a "dark" GRB in the afterglow era, preceding GRB 970828 in that category [1]. However, because of the chance superposition between 3EG J1621+8203 and GRB 970815, a slight doubt remains about the nature of AX/RX J1606.8+8130. *Chandra* observations are planned that should resolve the ambiguity of the possible connection between AX/RX J1606.8+8130 and either GRB 970815 or 3EG J1621+8203.

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